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Research Article

Lessons and challenges in creating alien species lists: insights from South Africa's national reports on the status and management of biological invasions

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Abstract

Information on alien species present in a country, their status (establishment, distribution, impacts), and how they entered and move around the country is crucial for effective management. Such information underpins regulations, allocation of management resources, and evaluations of current and future threats. South African regulations, first promulgated in 2014, mandate a triennial process of national reports on the status and management of biological invasions, requiring a consolidated list of alien species. Here we describe the process followed to create such a list, how the list evolved over time, and highlight lessons learnt and challenges encountered. Over the production of three status reports, there have been major improvements in how data were presented, how changes were tracked, and the degree to which the information was consistent with international best practice. The development of documented and repeatable workflows ensured clarity on why a species was included on the list and facilitated reviews and updates. The focus for future reports is to include all historical data sources and to put processes in place to incorporate new information as it becomes available. We conclude with a reflection on what has worked and identify eight recommendations for those developing national lists of alien species: 1. structure data and make them available; 2. use data standards and metadata; 3. list data sources and levels of confidence; 4. take a modular approach; 5. document workflows; 6. integrate with reporting requirements; 7. commit dedicated resources; and 8. learn by doing.

Key words: Biosecurity, checklists, inventories, non-native, standardisation, workflows

Introduction

Biological invasions are a major global threat to biodiversity and sustainable development, as highlighted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Thematic Assessment Report on Invasive Alien Species and their Control (IPBES 2023). The IPBES assessment highlighted that invasive alien species cause severe impacts on various sectors of society across the globe, which can be reduced through effective control measures (Roy et al. 2024). Biological invasions are also the subject of one of the 23 targets of the Convention on Biological Diversity's 2030 Kunming–Montreal Global Bio-

diversity Framework (GBF). Target 6 asks member states to "Eliminate, minimise, reduce and/or mitigate the impacts of invasive alien species on biodiversity and ecosystem services…" (CBD 2022). For these calls to action to be addressed, it is vital to know which invasive alien species occur where.

Lists of invasive alien species, particularly from countries in the Global South, remain incomplete, potentially leading to an underestimation of biological invasions and their impacts (McGeoch et al. 2012). These lists provide information on how many alien species are present in a country and, in some cases, their status (establishment, distribution, impacts), pathways of introduction and spread, and management. Such information is crucial to inform integrated governance (sensu Roy et al. 2024) and underpins regulations, allocation of management resources, and evaluations of current and future threats. The importance of national lists of alien species is emphasised in the GBF, with Target 6 aimed at reducing the introduction of "known or potential" invasive species by 50% by 2030 and eradicating or controlling invasive alien species, especially in priority sites (CBD 2022). To this end, there have been several global initiatives to develop lists of alien species for various regions and countries (e.g., Pagad et al. 2018; van Kleunen et al. 2019; Roy et al. 2020; Leihy et al. 2023). Compiling national lists and keeping them accurate and relevant is, however, challenging (McGeoch et al. 2012). Lists are dynamic and need constant updating as new alien species are discovered, species die out or are eradicated, and as new information on taxonomy, distribution, or impacts becomes available. As a result, national lists of alien species are never complete or perfect, but their value can be significantly improved by the adoption of a systematic, standardised process for collating and updating them that is transparent and evidence-based (e.g., McGeoch et al. 2012; Latombe et al. 2017; Vanderhoeven et al. 2017; Pagad et al. 2022; Zengeya et al. 2025).

South African regulations on biological invasions, first promulgated in 2014, mandated the production of triennial national reports on the status and management of biological invasions (Wilson et al. 2017). These reports (referred to hereafter as the "status reports") required a consolidated national list of alien species (see Zengeya et al. 2025). Here we provide a brief history of alien species lists in South Africa, outline the process followed to create the list for the status reports (finalised in 2017, 2020, and 2023), describe how the list evolved over time, highlight lessons learnt and challenges encountered, and reflect on what advice we would give to those starting out with the development of a national list of alien species.

A brief narrative of South African alien species lists

South Africa has a long and varied history of biological invasions and a similarly long and varied history of developing alien species lists, checklists, inventories, databases, and atlases (Faulkner et al. 2015; van Wilgen et al. 2020). Lists of alien species have been developed for specific taxa [e.g., the Southern African Plant Invaders Atlas (Henderson 1998)], sites [e.g., the first list of alien plants for Kruger National Park was published in 1937, with periodic updates since (Foxcroft et al. 2003, 2023; van Wilgen et al. in prep], and pathways [e.g., species in the pet trade (Nelufule et al. 2020)]. Lists were thus typically created to address particular needs. These one-off lists were often produced by one or a few curators and are rarely updated (Suppl. material 3).

In terms of regulatory lists (i.e., alien species that require management under South African law), various legislation dates back over a century, much of which was consolidated in the Weeds Act of 1937 (Act 42). Henderson and Anderson (1966) noted that "Lists… proclaimed for purposes of the application of the Act" included 37 taxa, a mix of alien and native plant species and families, though the lists themselves do not appear to have been promulgated. As far as we are aware, the first legislation that promulgated an explicit list of alien species was the revision of the Conservation of Agricultural Resources Act in 2001, which listed 198 alien plant taxa. The first comprehensive cross-taxon regulatory lists of alien taxa were published in 2014 as part of the Alien & Invasive Species Regulations under the National Environmental Management: Biodiversity Act (Act 10 of 2004) [NEM:-BA A&IS Regulations and Lists; see Wilson and Kumschick (2024) for details of the process followed, Wilson (2025) for the lists themselves, and Lukey and Hall (2020) for a broader review of the history of regulation in South Africa].

Lists of alien species as part of South Africa's status report over time

In response to the requirements of the NEM:BA A&IS Regulations, three lists were developed for the first status report by simply combining the various lists that existed: 1) alien species reported as present in natural ecosystems in South Africa; 2) alien species that do not occur in South Africa but that were listed in the regulations as either prohibited or invasive, or that have been eradicated from South Africa; and 3) alien species that do not occur in South Africa, were not listed in the regulations, but for which a "risk assessment" (as defined in the A&IS Regulations) had been completed. The lists from the first status report had several shortcomings – there were no metadata, there were several spelling errors, there was no standardised taxonomy, the sources were not documented, and the lists were only available as tables in the printed report (so they were neither readily accessible nor interoperable) (van Wilgen and Wilson 2018). For the second status report, the various lists from the first report were merged into one consolidated list and provided as a spreadsheet accessible to end users (http://dx.doi.org/10.5281/zenodo.3947659). In addition, the process to compile the list was more clearly laid out, allowing changes to be tracked over time. Metadata were included, as were sources of information and data confidence levels (low, medium, high), following accepted best practice [see SANBI and CIB (2020) for details]. However, there was still no clear standardised taxonomy, and, while much of the detail of how the list was constructed is available in the supplementary material, methodological information was not presented as a repeatable workflow. For the third status report, the metadata and structure were improved, making it possible to include ancillary enrichment data (though many of the data are still being collated) [see SANBI and CIB (2023a)]. There was also an effort to standardise the nomenclature used against a few key sources (Faulkner in press), and workflows were presented that documented the processes followed and decisions made [e.g., around taxonomy, nativity, occurrence status, degree of establishment, pathways, money spent, permits, and impacts; cf. SANBI and CIB (2023b)]. The process is being developed further as part of the upcoming fourth report (due 2026), but the vision is for it to become fully transparent and semi-automated, with clear workflows and processes to arrive at decisions where necessary (Fig. 1, Suppl. material 3).

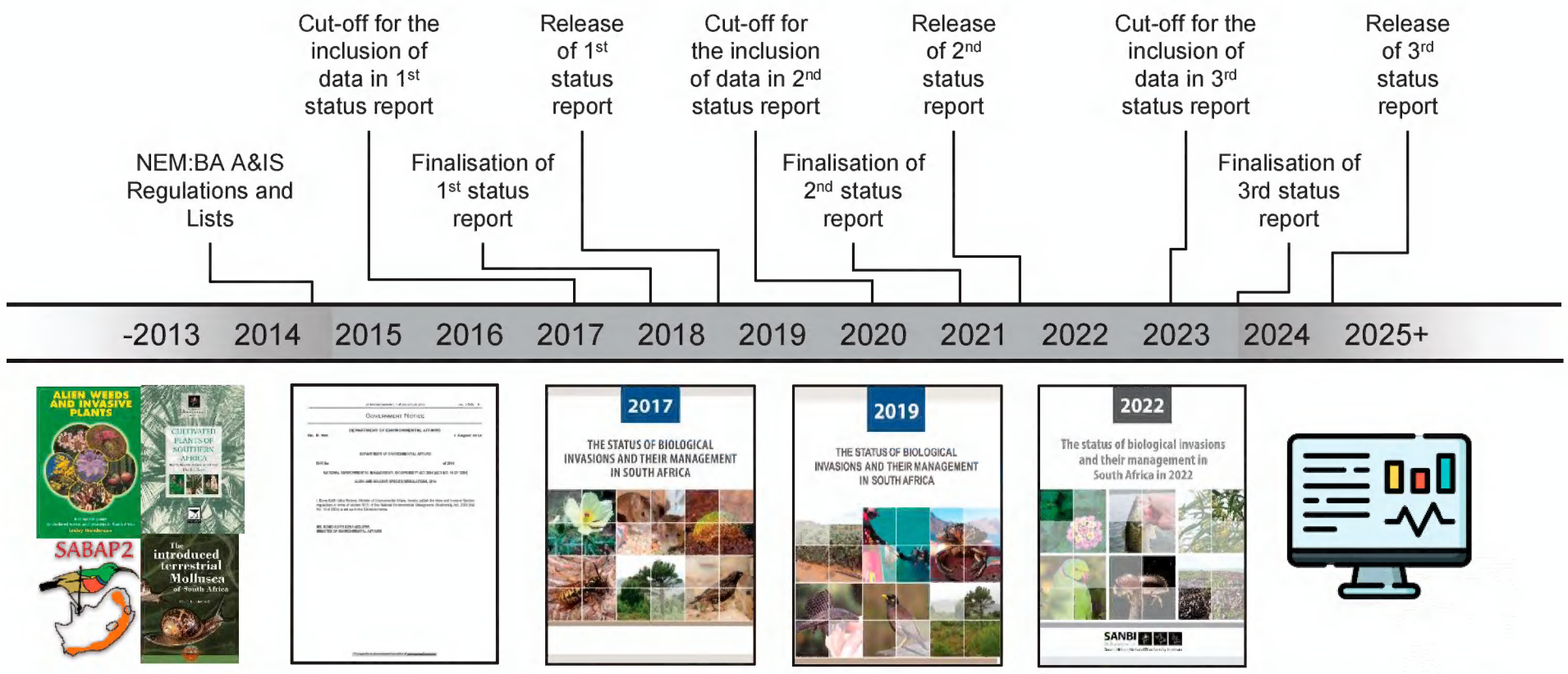

Cut-off for the inclusion of data in 1st status report
Release of 1st status report
Cut-off for the inclusion of data in 2nd status report
Release of 2nd status report
Cut-off for the inclusion of data in 3rd status report
Release of 3rd status report
NEM:BA A&IS Regulations and Lists
Finalisation of 1st status report
Finalisation of 2nd status report
Finalisation of 3rd status report
-2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025+
ALIEN WEEDS AND INVASIVE PLANTS
CULTIVATED PLANTS OF SOUTHERN AFRICA
SABAP2
The introduced terrestrial Mollusca of South Africa
Government Notice
2017
THE STATUS OF BIOLOGICAL INVASIONS AND THEIR MANAGEMENT IN SOUTH AFRICA
2019
THE STATUS OF BIOLOGICAL INVASIONS AND THEIR MANAGEMENT IN SOUTH AFRICA
2022
The status of biological invasions and their management in South Africa in 2022
SANBI
Various lists
Taxon- and site-specific lists (fewer lists based on pathways). Many published once and not updated. Lists developed to meet particular interests or goals
NEM:BA A&IS Lists
First consolidated cross-taxon lists, focused on those with environmental impact or threat. Based on expert opinion, revised by governmental officials, subject to public consultation. Future changes to be supported by risk analyses
1st status report
List developed based largely on mandated requirements for reporting with additional species added from readily available sources
2nd status report
Most information directly from the first report, but data easier to access, changes clearly tracked, and data presented in-line with international best-practice (e.g., Darwin Core). Focus on species with a reliable record of occurrence. Many sources still missing
3rd status report
Focus on making the data tidy and FAIR. Sources systematically included. Information not carried over if evidence not available. A greater number of sources incorporated. A separate list for the PEIs. Many sources acknowledged to still be missing
Vision: a dashboard
Consolidated data on all alien species that are or have been introduced to South Africa. Information is updated rapidly as new information becomes available through various data alerts and workflows with supervision as required. Data integrated with international data providers

Figure 1. How lists of alien species in South Africa have developed over time. For further details, see Suppl. material 3. PEIs: Prince Edward Islands (sub-Antarctic territories of South Africa).

Scope and purpose

Under the NEM:BA A&IS Regulations, SANBI was required to develop a report that considers "the status of listed invasive species and other species that have been subjected to a risk assessment". Given that the Act and relevant regulations are administered by the national department responsible for the environment, it is unsurprising that the focus has been on threats to the environment. The first lists focused on "taxa [that] impact upon, or threaten, natural ecosystems" (van Wilgen and Wilson 2018), but the scope of the list for subsequent reports was broadened from those regulated as 'invasive' (i.e., those on the regulatory lists) to include alien species regardless of where they are found, whether they have negative impacts, which taxonomic group they come from, and what stage of the introduction–naturalisation–invasion continuum introduced populations have reached (van Wilgen and Wilson 2018). To date, the list has not included human diseases, nor has there been a concerted effort to include agricultural crop pests and weeds, but there is no neat separation between transformed ecosystems (e.g., urban environments and agroecosystems) and "pristine" ecosystems (e.g., Hulme 2020; Potgieter et al.

2020), given that many protected areas are heavily influenced by human activities in South Africa (e.g., van Wilgen et al. 2025).

There have been challenges in including particular taxonomic groups in the list. Efforts have been made to interpret frameworks in invasion biology for micro-organisms (e.g., for forest pathogens, see Paap et al. 2022), but the biogeography has often not been elucidated for species, and biogeographic patterns may have eroded over time. The concept of a "species" is also often less clear. Invasions happen at the level of individuals (more precisely holobionts) interacting as populations rather than species (Colautti and MacIsaac 2004).

One decision made at the outset was that the definition of "invasive" should be based on biogeography and not on impact, thus aligning with Darwin Core standards (Groom et al. 2019). The rationale for this was partly that measures of impact are subjective, but also that impact and degree of invasion need not be tightly correlated (Ricciardi and Cohen 2007). In the list, information on the degree of establishment based on population processes (i.e., reproduction and spread from sites of introduction) is therefore clearly separated from information on negative impacts (environmental and socio-economic) based on specific schemes (Blackburn et al. 2014; Bacher et al. 2018). Information on possible positive impacts has not been routinely collated to date, but schemes are being developed to address this (e.g., Vimercati et al. 2022).

We believe it is important to try to include all species introduced to South Africa (even those in quarantine), on the basis that these species form an important component of the invasion debt (Rouget et al. 2016). There are, however, several species included that are known not to be present in the country. These include species listed as prohibited under the NEM:BA A&IS Regulations (i.e., may not be introduced); species recorded as present but that appear to have disappeared; and species recorded as present by error (see Matthys et al. 2025 for a proposed approach to address these issues). We believe that it is important to retain such species so that end users comparing lists over time can understand what has happened. Similarly, all names used historically for a given species are included in addition to the current accepted name.

Species that are native to one part of South Africa and invasive in another part of the country (Nelufule et al. 2022; Nelufule et al. 2023a, b) have been included. Notably, such native-aliens are only included if they pass the biogeographic criterion for being established, as it is infeasible to include all cases that are in captivity or cultivation. The list does not consider, however, native species that have undesirable impacts as a result of other aspects of global change (e.g., Nackley et al. 2017). For example, bush encroachment by native plants, the spread of native bird species into urban areas, and agricultural or ruderal weeds that are native. Such native species can present problems similar to alien species, but their management needs to be in the context of them as problematic within their native ranges (van Wilgen and Wilson 2018).

Metadata and data structure

In the first status report (2017), data were presented as several tables embedded in a PDF file, with limited metadata included as a preamble to the tables and therefore not in a systematic, searchable form. In the most recent version (2023), the

list is searchable, with a dedicated column for the data sources used to score most variables and the full references in a separate tab. This ensures transparency and allows those compiling and using the alien species list to retrieve and check original values – a clear improvement. The metadata aim to adhere to the Darwin Core data standards (cf. Groom et al. 2019), though this was not possible nor desirable for some variables included specifically for local reasons. For example, the variable *isNative*, which indicates whether a taxon is native to (at least a part of) South Africa, does not align with dwc:establishmentMeans, as terms like 'introduced' confound whether a taxon is alien to a region with its degree of establishment and introduction status (i.e., introduced, naturalised, or invasive). In addition, the Darwin Core standard for some biological invasion terms was substantially revised between the completion of the first and second status reports (Groom et al. 2019), and the updates are reflected in the list published with the third status report.

The nomenclature used is based on several taxonomic backbones. Non-plant taxa were checked against the Global Biodiversity Information Facility taxonomic backbone (GBIF; https://doi.org/10.15468/39omei), and plant taxa were first checked against the Plants of Southern Africa (NewPOSA; https://posa.sanbi.org) and, if information was not available, Plants of the World Online (POWO; https://powo.science.kew.org) (see Faulkner in press). If the datasets conflicted, the taxon name was flagged, and the original authors of the source were consulted to assist with verification. Some taxa were not listed in NewPOSA, POWO, or GBIF and needed additional user-defined taxonomic backbones. These included the International Plant Name Index (IPNI; https://www.ipni.org/) for plants, Nemaplex (http://nemaplex.ucdavis.edu/) for nematodes, and the World Register of Marine Species (WoRMS; https://www.marinespecies.org/) for marine animals.

The list in the third status report was produced in line with recommendations to make the data tidy (Wickham 2014) – each row refers to a species and each column to a particular variable with consistent units. The columns include information on species identity, taxonomic rank, status as an alien species, introduction dynamics, distribution, abundance, impact, legal status, information associated with regulatory status, and management. Detailed metadata are provided, with confidence and data sources for all of the 23 variables (Zengeya et al. 2025). The metadata for the list are freely available on Zenodo (SANBI and CIB 2023a) in a text-searchable format.

Sourcing data

Information incorporated into the list was obtained from various sources, including government reports, peer-reviewed papers, grey literature, atlassing projects, and online databases (Suppl. material 1). The information was obtained using three main strategies: 1) literature searches to identify relevant information and databases; 2) soliciting new syntheses, e.g., encouraging experts to contribute to a journal special issue (Wilson et al. 2017) and an encyclopaedic book on the status of biological invasions in South Africa (van Wilgen et al. 2020); and 3) direct requests to stakeholders for specific inputs. The number and type of sources used to inform the list have increased over time (Fig. 2). In the first status report (2017), information was obtained from 42 sources, comprised mainly of government or institutional reports, expert opinions, and peer-reviewed literature. The number of sources more than doubled in the second status report (2020), with over 1,000

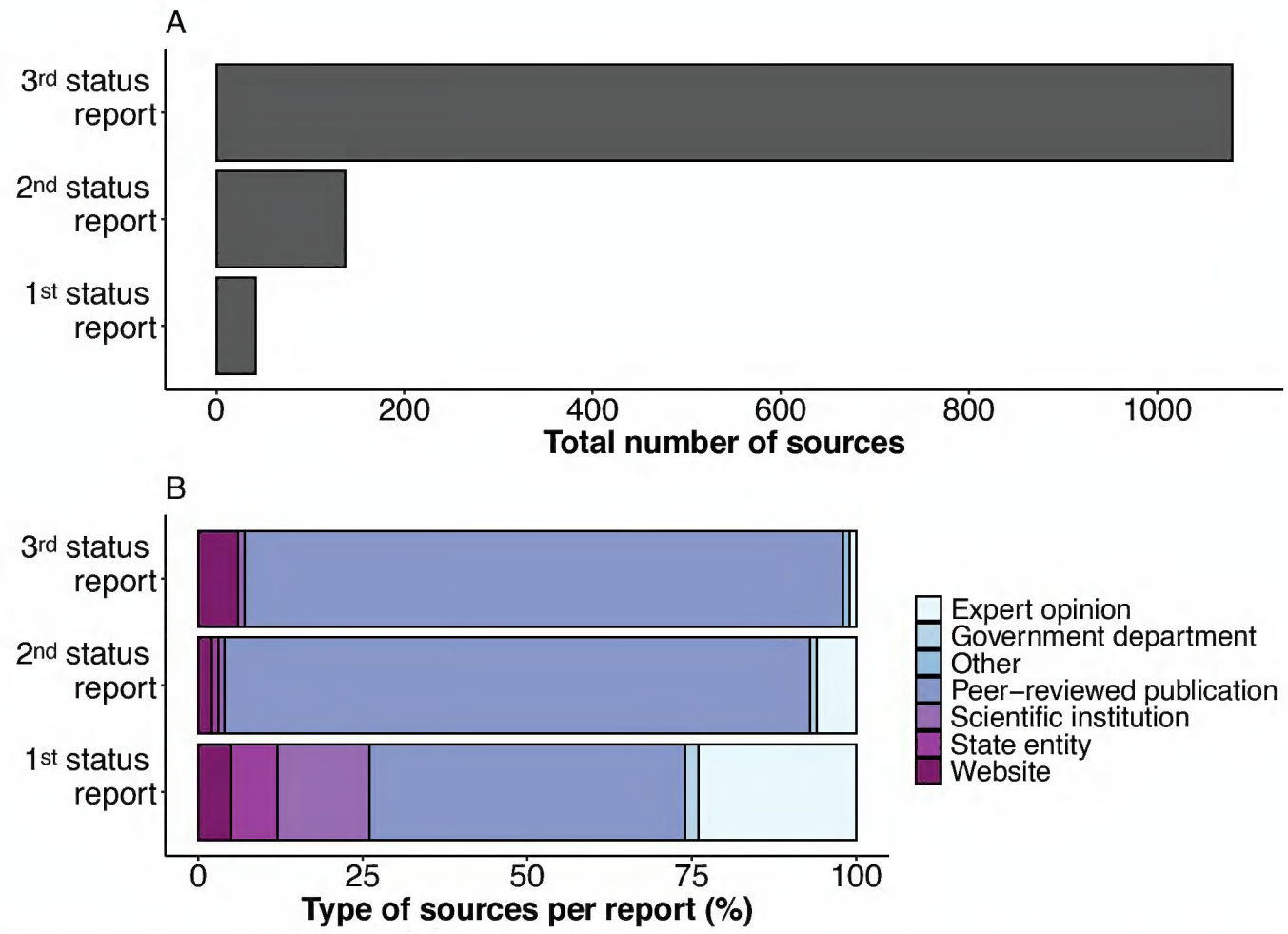


Figure 2. The (**A**) number and (**B**) type of sources used to populate the lists of alien species compiled as part of South Africa's national reports on the status and management of biological invasions. For a database of sources, see Suppl. material 1.

sources used in the third status report (2023). The increase in data sources was mainly due to an increase in the use of peer-reviewed publications and online databases and the deprecation of evidence based on expert opinion.

Processing data and workflows

Information about the taxonomy, occurrence status, degree of establishment, and introduction status of a given species was obtained from various sources with different levels of confidence and completeness. In the first two status reports (2017 and 2020), the process of extracting and translating information from original data sources was not properly documented. This was improved in the third status report (2023) by creating a database of sources and intermediary files detailing what information was extracted from the original databases. This information was then standardised based on the schema outlined in the metadata (SANBI and CIB 2023a). Issues were flagged and noted in the intermediary files, such as unresolved terms, missing data, and any translated names and interpretations. The intermediary files were then manually merged by standardised names and unification of ancillary data. To mitigate individual subjectivity, all intermediary files were cross-checked against the metadata by at least one of us.

Several workflows were developed to outline the process used to compile the list. The process for the first status report was captured as methodological notes in the report itself (van Wilgen and Wilson 2018). The second status report (2020) included details of how the list was compiled in the supplementary material (Zengeya and Wilson 2020b). The third status report (2023) specifically presented discrete workflows for various aspects used to compile the report (SANBI and CIB 2023b). These include a protocol of how to add alien species and enrichment data to the species list and an automated process to check taxonomic information

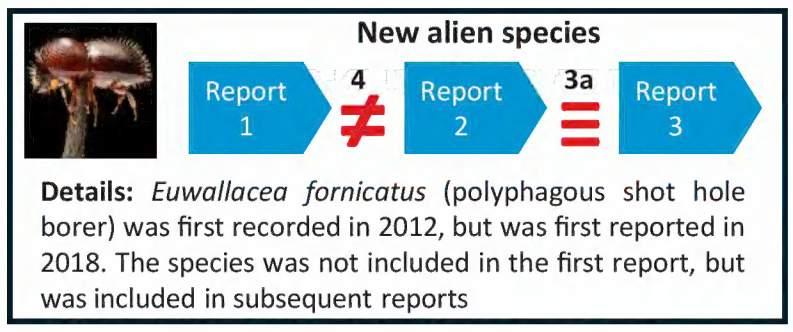
(see Faulkner in press). These workflows are intended to be step-by-step guides as to where to source data and how such data should be collated, processed, and analysed. The intention is that the process to compile the list is transparent and can be readily repeated. Some of these workflows required specific protocols with the intention that they be applied for purposes other than the status report or for other regions. For example, protocols have been developed to classify native-alien populations (Nelufule et al. 2022), to estimate the monetary cost of biological invasions (McCulloch-Jones et al. 2024), and to incorporate findings from molecular analyses (Fernández Winzer et al. 2025a). For future status reports, the vision is to develop, curate, and maximise automation of workflows for various compilation processes.

Tracking change

A typology of change was developed during the production of the second status report (Zengeya and Wilson 2020a) and is used to track why values change between iterations of the list (Fig. 3). Based on the typology, there are five reasons why values change: data are no longer relevant; data are reinterpreted; new data are collected; confidence levels change; or there is a 'true' change. A 'true' change (type 4 in Fig. 3) is when there is an actual change in biological invasions, such as when the introduction status of a species changes from 'naturalised' to 'invasive' as it begins to spread (Suppl. material 2). When a change is made, the type of change is documented in a change tracker, and the number of changes and reasons are presented in the status report (or in its supplementary material). Thus, it is explicit where and why changes were made. Estimates of trends in biological invasions require true change (type 4 in Fig. 3) to be calculated from a revised baseline that accounts for all other types of changes (types 1, 2, and 5 in Fig. 3; for type 3 there is no change in actual values, although the confidence in an estimate might increase as new information becomes available). The typology of change, therefore, assists with documenting and interpreting change and with the calculation of trends. It also informs proposed actions in response to changes. For example, in cases where errors were corrected, the existence of these errors should be communicated to those who compiled the original data; or in the case of true change, management may need to be adjusted (e.g., a change in how a species is regulated may be required if it is under complete biological control).

Data mobilisation and reporting

The list is freely available on Zenodo (Zengeya et al. 2025), making it findable, accessible, and easy to use for end users. The data on the list are used to calculate the indicators that form the backbone of the status report (Wilson et al. 2018), with visualisations and summary statistics presented. The status report itself is published as a static document every 3 years, but it is expected that, in the future, the data, visualisations, and summary statistics will be provided to end users through an online dashboard that is updated as new information becomes available. Summaries would then be generated, with detailed assessments of broad issues being regularly published, or as needs arise. Currently, the list is not harmonised with other external datasets (e.g., South Africa's GRIIS list, Robinson et al. 2020), but it is expected that this list will form the basis of future GRIIS lists and others as far as possible. This will reduce the differences between the various lists.


New alien species
Report 1
4
Report 2
3a
Report 3
Details: Euwallacea fornicatus (polyphagous shot hole borer) was first recorded in 2012, but was first reported in 2018. The species was not included in the first report, but was included in subsequent reports
Uncertainty captured
Report 1
3a
Report 2
3b
Report 3
Details: Piophila casei (cheese fly) was listed in all reports, but the type specimen of a related species was found in South Africa, resulting in confusion on the origin of the group. This uncertainty was captured in the third report.
Species name change
Report 1
3a
Report 2
3a
Report 3
Details: Water hyacinth was listed under the name Eichhornia crassipes in the first and second reports, but the species name was changed, and it was listed under Pontederia crassipes in the third report
Directed research results in inclusion
Report 1
3a
Report 2
5
Report 3
Details: Chinchilla chinchilla was not listed in the first and second reports, but was likely in the country. Directed research on the pet trade in mammals resulted in its inclusion in the third report.
Errors
Report 1
3a
Report 2
1
Report 3
Details: Daktulosphaira vitifoliae (grape phylloxera) was listed twice in the first and second reports: under the accepted name (Daktulosphaira vitifoliae) and a synonym (Viteus vitifoliae). This was corrected in the third report.
New data requires re-interpretation
Report 1
2
Report 2
3a
Report 3
Details: Gonipterus scutellatus, which was listed in the first report, is a species complex. Genetic analysis confirmed the species in the country is 'Gonipterus sp. 2'. Both are listed in subsequent reports.

Types of changes	Description	Reasons
1 Report t ⊘ Report t+1	Data collected for a previous report but are no longer relevant	• Change in indicators • Errors
2 Report t Δ Report t+1	Data were collected for a previous report, but need to be reinterpreted	• Change in indicators • A change in the data (e.g., a species has split into two taxonomic units, or new regulations are developed)
3a Report t = Report t+1	Data were collected for a previous report, and there is no change in the values	• No new data were found • New data support the previous data • New data results in changes, but not to values (e.g. there is a change to the species name)
3b Report t ≈ Report t+1	Data were collected for a previous report and while the value has not changed, the confidence changed	• The confidence has changed (new data either support the previous data or cast doubt on the value) • More rigorous application of indicator values
4 Report t ≠ Report t+1	Data collected indicates the value has changed since a previous report	• Data collected since publication of previous report • Data were collected before publication of previous report, but not included in previous report
5 Report t Ø Report t+1	Data collected where no data were available for previous reports	• Data were not available previously, and were collected since publication of previous report • Data were collected before publication of previous report, but not included in previous report • The specific indicator is new

Figure 3. Details on the types of changes that can occur between versions of alien species lists, with examples from the national reports on the status and management of biological invasions in South Africa (see also Suppl. material 2). This typology assists with documenting, interpreting, and tracking changes. Photos: Garyn Townsend (*Euwallacea fornicatus*), Andrew Meeds (*Piophila casei*), Symoum Syfullah Priyo (*Eichhornia crassipes*), Jaime E. Jimenez (*Chinchilla chinchilla*), Czif-commonswiki (*Daktulosphaira vitifoliae*), and Rosa Knoppersen (*Gonipterus* sp. 2).

The list, once corrected for changes other than 'true' changes, is intended to be used to inform the management and regulation of alien species in South Africa. For example, if a species' invasion status changes from 'presentAsAlienNotNat-

uralised' to 'NaturalisedNotInvasive' as it has escaped from captivity, then, depending on the risks posed, an incursion response may be considered. Similarly, a species whose invasion status changes from 'NaturalisedNotInvasive' to 'Invasive' as it spreads might need to be reassessed in terms of how it is regulated and how much of a priority it is for management.

The list was initially developed to report on the status and trends of biological invasions at a national level; however, it is expected to be used to monitor and report on progress towards Target 6 of the GBF (CBD 2022).

Discussion

South Africa's national alien species list

Over time, there have been major improvements in how data on alien taxa in South Africa are presented, how changes are tracked, and the level of adherence to international best practice (Fig. 1). For future updates, missing key historical data sources will be incorporated into the list, workflows to formalise processes will be developed (e.g., Matthys et al. 2025), and systems added to incorporate new information as it becomes available [e.g., Faulkner in press, Fernández Winzer et al. 2025a].

It is clear several challenges remain, such as significant gaps in knowledge of the presence and distribution of taxa not currently covered by specific atlassing projects. The numbers of alien terrestrial plant species and vertebrate species are well documented as a result of atlassing projects such as the Southern African Bird Atlas Project 2 (SABAP2) (http://sabap2.birdmap.africa/), the Botanical Database of Southern Africa (BODATSA) (http://posa.sanbi.org/), and the Southern African Plant Invaders Atlas (SAPIA). However, there is less information for other groups such as invertebrates, soil organisms, and microorganisms (Janion-Scheepers et al. 2016; Wood 2017; Paap et al. 2018; Janion-Scheepers and Griffiths 2020). Integration of GBIF with citizen science platforms such as iNaturalist and the digitisation of historical records from natural history collections has increased knowledge on the distribution of alien species (Zengeya and Wilson 2023). Unfortunately, a decline in active surveillance for plants because of a hiatus in SAPIA has reduced our ability to track plant invasions across South Africa. In addition, there are few reliable data sources on species' relative abundance (cover, biomass, or population size) at specific sites. Remote sensing is a promising approach to improve distribution data, but so far there are few useful results to assist with compiling the list (but see Cardoso et al. 2025; Kotze et al. 2025). Only a few species have been assessed formally for impacts – more information needs to be evaluated and systematically incorporated (Zengeya et al. 2020; van Wilgen et al. 2022).

Lessons learnt

We identified several key lessons during the development of a consolidated list of alien species for South Africa, including necessary elements for transparency and collaboration (e.g., the need for data to be FAIR and tidy). We believe the following insights can assist others that are setting up processes to compile similar lists.

1. Structure data and make them available – so data are 'Findable', 'Accessible', 'Reusable', and tidy (see Wickham 2014; Wilkinson et al. 2016). For exam-

ple, the list of alien species in South Africa is findable on the online repository Zenodo (http://dx.doi.org/10.5281/zenodo.7433102). Each published iteration of the list has a Digital Object Identifier (DOI) to ensure that it can be appropriately cited and located and that information can be updated and changes tracked. The list is currently made available as a static database as a worksheet (.xlsx), accessible for most users, although it is a proprietary format that can have issues with interoperability. The list information is reusable since it is easy to determine who generated the original data, and permission is granted for others to use the data (the status reports are produced under CC-BY-NC licences). The list was also produced in line with recommendations to make the data tidy, which makes it easier to manipulate – each row refers to a species and each column a particular variable with consistent units.

2. Use data standards and metadata – so terms are used consistently, i.e., 'Interoperable'. Biodiversity monitoring requires access to rapid, reliable, and repeatable monitoring data that can be used to inform policy, decision-making, and interventions (Groom et al. 2025). Providing such information – from local to global levels and within timescales relevant to policy – calls for improved integration of data on biodiversity from different sources such as citizen scientists, natural history collections, and researchers. Interoperability allows datasets and metadata to be merged easily across different applications. Lists should adhere to international best practices for biodiversity data, such as the Darwin Core standards (Groom et al. 2019). Standardised data formats and protocols enable the list to be interoperable among stakeholders such as researchers, collections (museums and herbaria), citizen science platforms, and global initiatives (e.g., GBIF) (see also 6. Integrate with reporting requirements).
3. List the data sources used and the level of confidence – to facilitate checks and updates and mitigate uncertainty. Listing data sources improves trust in the list, as it allows verification and checks of sources consulted. It also helps track changes as new information is added and old information is either deprecated or updated. From our experience, adding information that is not clearly sourced makes it difficult to resolve errors, generating lengthy and inconclusive discussions. The level of uncertainty varies among data sources due to the methods used to collect the data and the completeness and relevance of the data sources, calling for a process to mitigate these differences. To this end, we assigned confidence levels (low, medium, high) following accepted best practice.
4. Take a modular approach – so it is easy to add detailed information for well-known species while retaining coarse information for less-known species. The modular process to compile a national list of alien species (e.g., McGeoch and Squires 2015; Latombe et al. 2017) facilitates collection of baseline data. This is important as countries differ in their level of existing information on alien species and in the resources and capacity available to collate existing data and to generate new data. A modular approach makes it possible to systematically add new information or resources as they become available.
5. Document workflows – so the process can be understood, errors are found and corrected, and the process can be replicated [and ultimately (semi-)automated]. The development of documented and repeatable workflows ensures it is clear why species (and associated information) are included and facilitates reviews and updates. Documented workflows also assist with the automation and standardisation of the process and reduce the burden of regular monitoring and re-

porting by decreasing the time between information being collected and when it is incorporated into the list (cf. Fernández Winzer et al. 2025a). The workflows used to compile the list of alien species in South Africa are available (http://dx.doi.org/10.5281/zenodo.7433129) for others to consult, trial, and adapt to their own needs. We would appreciate feedback on how to improve the workflows and to gain insights on how useful the workflows are to other countries.

6. Integrate with reporting requirements – so the lists are directly used. One motivation for creating national lists of alien species is to facilitate reporting under national and international conventions. Integrating with existing processes and reporting requirements helps to incentivise stakeholder participation (e.g., Díaz-Reviriego et al. 2019; Krug et al. 2020), promoting inclusivity, enhancing knowledge, increasing relevancy, and improving the effectiveness of interventions (Nuñez et al. 2024). Regular monitoring of biological invasions will facilitate South Africa's reporting to international conventions, including Target 6 under the GBF, and a process has been initiated to integrate South Africa's list with the Global Register of Introduced and Invasive Species (GRIIS) (Pagad et al. 2022). The current list (Zengeya et al. 2025) will be used to revise the GRIIS list for mainland South Africa, similar to what has already been done for the Prince Edward Islands (sub-Antarctic territories of South Africa; Fernández-Winzer et al. 2025b).
7. Commit dedicated resources – so lists can be curated and updated, and there is a clear line of communication for data providers and users. From our experience, it takes a lot of time, effort, and expertise to compile and curate national lists. It is therefore vital to ensure sufficient resources and capacity for a sustainable process, including finances aimed at attracting and retaining skilled personnel to oversee and develop processes. Lists are also inherently complex and require expertise on different aspects of biological invasions, such as data management, taxonomy, pathways, and management; therefore, any project plan needs clear roles and responsibilities. In South Africa, the compilation of the list is coordinated through a national institution (SANBI) by a small core team that draws on inputs from a managed network of stakeholders from an active community of practice in biological invasions (Byrne et al. 2020; Wilson et al. 2017). Coordination through a national hub reduces duplication with stakeholder consultations, promoting buy-in and saliency of the list. Sustained government funding (albeit with some uncertainty at times) has proved essential. Many people are needed to spot errors and provide updates, but we recommend having a specific, dedicated custodian of the list who is responsible for making the actual changes.
8. Learn by doing – during the initial phase of developing a national list, it is better to work with the resources available and document processes, feedback, and corrections, knowing there will be setbacks and mistakes. We accidentally embraced the concept of adaptive learning (i.e., learning by doing and developing systems over time). This was partly because, when compiling the first status report of 2017, there were no local comparable processes to draw on, and we adapted to new approaches and data standards as they became available. For example, the Darwin Core standard for some biological invasion terms was substantially revised between the completion of the first and second status reports (Groom et al. 2019). The process of devising the metadata was done in parallel with data entry, and this proved challenging. However, the back and forth improved both the metadata and how information was

collated. The metadata has now largely matured, and future updates will be hopefully done without significantly disrupting other processes. If we were to start again, we would clearly document all processes and changes and avoid ad hoc tweaks. This inevitably leads to a slower and somewhat less responsive process, but it is more sustainable and means you can learn by doing.

We have also learnt and improved our processes by adopting practices from other initiatives on compiling lists, such as the Tracking Invasive Alien Species (TrIAS) project (Vanderhoeven et al. 2017, https://osf.io/7dpgr/wiki/home/) and the Biodiversity Building Blocks for Policy (B-Cubed) project (Groom et al. 2025, https://b-cubed.eu/). The aim of the B-Cubed project is to develop pipelines to improve integration of biodiversity data into data cubes to be used for models and indicators of biodiversity monitoring. Such data cubes, models, and indicators are expected to feed into the process of revising our list of alien species by providing information that will help address three of the six identified key gaps in previous status reports (alignment of indicators, mobilisation of spatial data, mobilisation of impact data) and assist with the automation and standardisation of the process and how the status reports are communicated (e.g., including workflows and dashboards). In addition, the B-Cubed project has developed a number of guidelines, training programmes, and activities such as videos and interactive short courses to explain processes and workflows. These tools are freely accessible and intended to increase capacity in biodiversity monitoring (https://docs.b-cubed.eu/). Specific to South Africa, a stakeholder workshop will be held to showcase our end-user experience in using tools developed under the B-Cubed project to assist the process of developing our national alien species list.

Conclusion

The process of compiling a national list of alien species is a daunting task that requires dedicated resources, expertise, and commitment. National lists of alien species are never complete or perfect. Lists are dynamic and need constant updating as new alien species are discovered, populations die out or are extirpated, and as new information becomes available. Therefore, lists should not be viewed as an end per se but as a pragmatic process capturing the current state of knowledge that can be improved as better technology, expertise, and information become available. We argue that it is essential that lists are compiled and updated using systematic and standardised processes that are transparent and evidence-based. This facilitates checks and updates and allows for a process to be put in place to mitigate uncertainty around sources of information. Reflecting back on our experiences, the eight recommendations highlighted are what we consider to be key elements that others should consider when planning to compile a list of alien species. We welcome insights from elsewhere on other issues faced and tips on how to address them.

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Additional information

Conflict of interest

TZ, KF, and JW were part of the editorial team for the special issue 'Developing lists of alien taxa in the Global South: workflows, protocols, processes, and experiences', but they took no part in the peer review and decision-making process for this paper.

Ethical statement

No ethical statement was reported.

Use of AI

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Author contributions

Conceptualisation: JW, KF, TZ. Methodology; Data curation; Writing – original draft; Writing – review and editing: All.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Full list of data sources used (Name, Description, Scope, and When incorporated)

Authors: Tsungai A. Zengeya, Katelyn T. Faulkner, Masingitla P. Mtileni, John R. U. Wilson

Data type: xlsx

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Link: https://doi.org/10.3897/neobiota.101.162932.suppl1

Supplementary material 2

How the introduction status of a species might change through time (specifically between status reports)

Authors: Tsungai A. Zengeya, Katelyn T. Faulkner, Masingitla P. Mtileni, John R. U. Wilson

Data type: docx

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Link: https://doi.org/10.3897/neobiota.101.162932.suppl2

Supplementary material 3

A summary of the various lists of alien species in South Africa over time, with details of what information they contain, how they were constructed, and by whom

Authors: Tsungai A. Zengeya, Katelyn T. Faulkner, Masingitla P. Mtileni, John R. U. Wilson

Data type: docx

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